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Providing measured position data for agricultural machinery

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Abstract

Agricultural machinery and vehicles require position data for guidance and to control implements for optimal working positions. Position data are also needed for such applications as precision farming. The necessary accuracy, resolution and frequency of position data vary according to the specific application. Only one system, installed at a central vehicle (e.g. the tractor), should provide position data for each task. The basic concept for the proposed central system is that position data are calculated in accordance with the application and transferred directly to the point at which they will be used. The paper describes the fundamentals of measurement and calculation of position data, and gives a short introduction to the existing agricultural networks to transfer these data. It concentrates on a proposal for a network service to provide and transfer position data. The solution discussed is based on the agricultural BUS (DIN 9684, ISO 11783). © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Local area network; Controller area network; Agricultural BUS system; LBS; Calculation of position; Calculation of direction; LBS service

1. Introduction

The purpose of position guidance is to bring the means of production to the plants, which grow at a fixed location on the field. The plants, or rather their location on the field surface, are the reference for guidance. Position data are needed to guide agricultural vehicles, to control implements and to support precision farming. Accuracy, resolution and frequency depend on their application.

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It must be emphasized that this paper does not address the problem of suitable sensors to generate the data. Rather, the problem studied here is that a position signal is generated with reference to a certain location on the mobile unit, but this position is not identical with the location where the position data are needed. Moreover, position information may be needed for several purposes at the same time, and the configuration of the vehicle–implement combination may change frequently.

As mentioned by Freyberger and Jahns (1999), Wilson (1999), the measuring system can either be an absolute position system, such as the satellite system described by Bell (1999), or a relative system, such as the machine vision systems described by Debain et al. (1999), Hague et al. (1999). It may also include auxiliary sensors.

Sensor systems measure position only in reference to a specific location, such as the mounting point of the camera or the foot of the aerial. In the following presentation, this location is called the measuring point. For various reasons, the location of this measuring point is predetermined, meaning the satellite antenna will be mounted as high as possible on the roof of the tractor cab to minimize shading. A camera will be mounted where optimal view is guaranteed. Movement caused by rough or sloping field surfaces may cause the measured position and the position on the field surface to differ widely. For example, for a vehicle with a satellite antenna mounted on top of the cab, at about 3.5 m, driving on a sloping surface of 10°, the difference in direction of the inclination will be about 60 cm. Fig. 1 illustrates this scenario for one dimension. In this example, it may be appropriate to calculate the position of a reference point. Bell (1999) proposes the middle rear axes of the

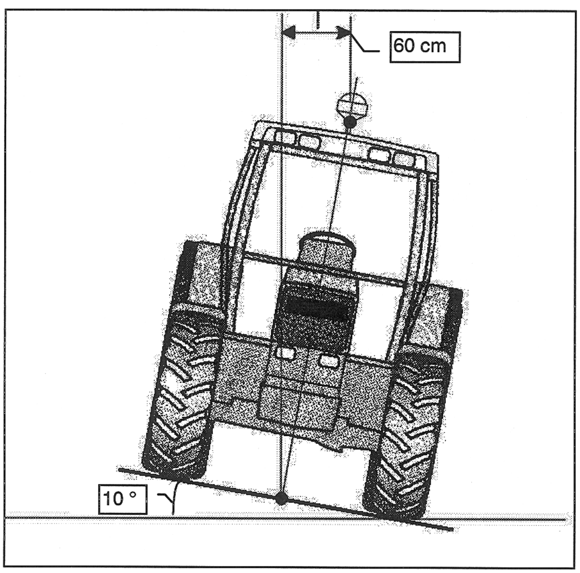

Fig. 1. Difference in position for two locations due to sloping terrain.

tractor as a reference point. A point in the field surface, for example, vertical under the middle of the rear axis seems more appropriate for some applications. For certain applications, such as the control of implements, the position of a certain point of the implement may be of final importance. This point will be called the target point.

In cases where position data are needed for different purposes, it is not very efficient to measure the position for each purpose separately with an independent measuring system. Multiple hardware can be avoided when the position is measured only once, and the positions of the other points on the vehicle or implements are calculated. This is possible if position and attitude are measured, and the spatial vector between the measuring point and the point to be calculated is known. If both points are rigidly coupled, meaning that both points are on the tractor, the vector between these points is constant, and a simple matrix calculation yields the result. If these points are not rigidly coupled, meaning, for example, that one point is on the tractor and the other is on an attached implement, the vector is variable. Additional measurements become necessary to establish the vector between these two points or other principles to calculate the position of the target point must be applied.

2. Data processing and data transfer

Position data of any point on the vehicle or implement can be calculated from the position and attitude measured at a measuring point. This calculation can be made by the measuring system (central data processing) or by each system requesting target position data (distributed data processing).

2.1. Distributed data processing

The measuring system serves only as an intelligent sensor in the case of distributed data. It measures position and attitude on request, and provides these data without any processing. Characteristics such as frequency and accuracy are determined by the requesting unit. This unit performs all processing to calculate the position. The unit must know the position of the measuring point and all relevant parameters to do this. The advantage of this procedure is that the measuring device can be relatively simple. On the other hand, each requesting unit needs the full capacity to perform this calculation.

2.2. Central data processing

The measuring unit is extended by components to calculate the position of target points for any user. This measuring and processing system forms one unit of a so-called position and navigation service (PNS), which provides final position data of any target point. In this case, only one measuring and processing system is necessary even when position data are requested by more than one user. To do so, only the PNS must know all of the relevant parameters for the calculation.

2.3. Data transfer

A data transfer is necessary no matter where the data are processed. For such a data transfer, a standardized network is appropriate. For agricultural purposes, a BUS for data transfer between mobile units and stationary farm computers exists. The agricultural BUS system (LBS) has been standardized to exchange information between the electronic units (LBS participants or BUS nodes) in a network. The standard defines the physical layer of the network, network protocol, system management, data objects and central services for common tasks (Speckmann and Jahns, 1999).

The LBS has been standardized as DIN 9684 (DIN, 1989–1998). Currently, efforts are being made to establish an international standard (Nienhaus, 1993), ISO 11783, for such purposes. Like LBS, ISO 11783 will also define an agricultural BUS as an open system to exchange data on agricultural machinery, particularly on tractor–implement combinations and from the mobile units to the stationary farm computer. The standards are based on the controller area network data protocol (CAN; BOSCH, 1991). Corresponding hardware is on the market.

In the LBS, data objects are defined for the transmission of general position data (geographical positions: longitude, latitude, altitude, or position in a tramline). The standard allows definition of additional data objects such as multidimensional distances, directions and speeds. No data objects exist presently in the LBS for geometric implement parameters. ISO 11783 provides, in Part 7 (Implement Messages Application Layer), the first definitions of implement navigational offsets. Current standards do not define where which data are processed. Therefore, it is immaterial on which unit the BUS calculates the data for the target point, and which unit or units measure the data.

The LBS provides so-called LBS services to execute common tasks. LBS services are functional units, which perform frequently recurring tasks for LBS participants. Such a service is the LBS user station. This is a central interface to the user (operator) for input and output of data which is at the disposal of any node (LBS participant) on the BUS. Another service provides the data exchange between the mobile unit and the stationary computer, the farm computer. Some more services are named in the LBS but not yet standardized in detail, such as for diagnosis services or the service 'Ortung und Navigation' (position and navigation), which will be discussed in the following as PNS. In Fig. 2, an exemplary simplified scheme of an agricultural network is shown for a tractor–sprayer combination. This scheme includes the physical BUS line, which is the backbone of the network. At this BUS, participants such as electronic control units (ECUs) of the tractor and sprayer are coupled. Additionally, two LBS services are connected on the BUS. One of these services represents the LBS user station. The other is the LBS service 'position and navigation', with the measuring and processing system for position data.

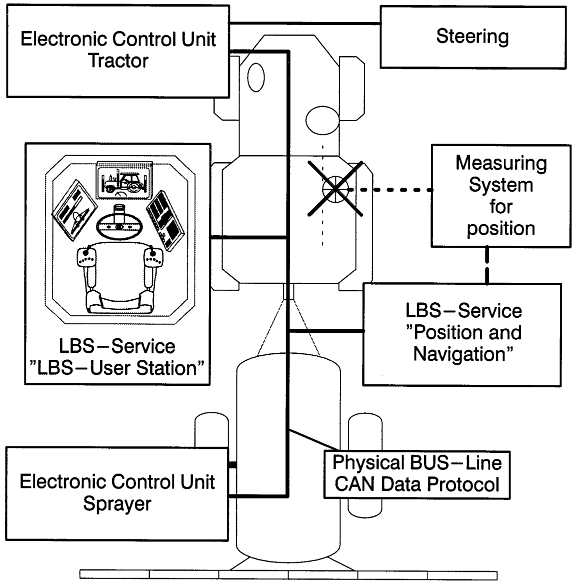

Fig. 2. Scheme of an agricultural network in a tractor–sprayer combination.

2.4. Comparison of distributed and central data processing

For a distributed data processing, the agricultural BUS, according to DIN 9684 or ISO 11783, defines the necessary data exchange between the measuring system and any participant; respectively, any ECU. The question how each ECU gets geometric and kinematic parameters that are necessary to compute position data remains open. Each ECU knows its own parameter from its coupling point to the target point, but it does not know the parameter from the coupling point to the measuring point. These parameters must be provided from other ECUs. None of the standards define corresponding data objects or procedures requesting the data. For distributed data processing, these definitions have to be supplemented.

Also, for central data processing, all kinematic parameters between the measuring point and the target point must be known. In addition, methods are to be defined for the use of the central service with regard to the calculation of position data of target points. A position and navigation service requires an extension of the standards, but the following advantages in practical use are essential:

- To determine the position data of a target point, the corresponding ECU has only one dialogue partner in the network. It works independently from the respective network configuration, delivers only its own parameters and receives only its specific position data.
- The PNS receives parameters from all ECUs. It knows all geometric conditions and kinematic parameters of the vehicle–implement combination. Thereby, an unambiguous determination of the position of any target point is possible.

- The standard defines the procedures to calculate and present the position data of a target point unambiguously.
- The computing performance to calculate the position data is provided solely by the PNS. No computing capacity is needed for this purpose from the ECUs.

As mentioned in the previous section, a service to provide position and navigation data is already planned in the LBS. In the following, a sample solution of a PNS is presented.

3. Proposal for a positioning and navigation service

At this time, it should be mentioned that the following description of a PNS is a proposal. It provides a platform for discussion, which may lead to the standardization of such a service.

3.1. Main features of a PNS

The features of a PNS depend, first of all, on the purpose for which it will be used. From the foregoing, it is clear that position data are measured at one location and used at different locations. The following requirements must be fulfilled to provide the data needed to guide a vehicle, to control positions of implements and to assist any kind of precision farming:

The PNS provides data related to the measurement point(s).

The PNS provides data related to the reference point(s).

The PNS provides data related to the target point(s).

The characteristics of such a service are as follows:

1. The way the data are requested and transmitted is already standardized and defined by the LBS (DIN 9684) and will be standardized by ISO 11783. Therefore, it will not be discussed here. In the following, LBS will be used as a standardized agricultural BUS system.
2. The volume, accuracy, frequency and range of the data are determined by the purpose of the data.
3. The hardware and software to fulfil these demands should not be standardized, but be determined by the manufacturers.

3.2. Influence of the standard on measuring and calculation methods for position data

The kinds of measuring systems and methods used to determine position data by the PNS is not in the scope of the standard. Systems based on satellites, machine vision, inertial navigation, geomagnetics or a combination of these may be applied. As a consequence, the manufacturer may determine how to generate the position data as long as he meets the stated requirements and accuracy.

3.3. Integration of the PNS into an agricultural BUS system

There are some benefits of integrating the positioning and navigation service into the LBS, because many characteristics are already defined. The LBS already includes the option of a PNS as part of the standard. It allows the realization of a service either as an independent physical unit or as a logical unit inside of another physical unit. The physical properties of the BUS interface and the BUS protocol (DIN 9684, part 2) are defined by the standard. For integration of the service into the LBS, the definitions of the system functions are decisive (DIN 9684, part 3). They define the performance of the nodes at the LBS. Part 3 also gives the general definitions of LBS services.

An LBS service forms a point-to-point link with LBS participants. The use of a service by an LBS participant can neither be influenced by other users, nor can an LBS participant influence links between the service and other participants. All further definitions of the PNS are not yet standardized.

3.4. General mode of operation of the PNS

For the design of the PNS, the following basic assumptions apply:

1. Each ECU knows only its parameters, meaning coordinates and numbers of reference points, target points, positions of couplings, vehicle types or wheelbases.
2. Only the ECU can define necessary time intervals, accuracy and resolution for position data, depending on the working conditions.
3. Each ECU can get different position data at arbitrary times.
4. Parameters and the way of calculating and providing position data will be defined before the working processes of the field machinery are started.
5. The PNS provides a library of procedures to calculate position data for standard implement and vehicle types.
6. Position data are provided automatically (cyclically) or on demand.

To meet these requirements, the service provides the tools, and the ECUs determine how and which tools are used. This means they define one or several task(s). Such a task basically represents a list that includes commands to activate the specific tools. These tasks are sent to the PNS, which subsequently performs these tasks. Different tasks of one ECU are executed independently of each other.

Fig. 3 illustrates the data transfer between the PNS and one ECU. It also shows the main parts of the PNS. The tools of the PNS include the system for measuring the position and attitude data of the measuring point, and a library of methods to process these data. Methods exist:

- to calculate position data (position methods);
- to calculate mean, maximum, minimum and integral values of position data (arithmetic methods);
- to export and import data (transport methods);
- to send data to the ECU (transmission methods); and
- to control the data processing (data control methods).

For some of these methods, the ECU has to define corresponding parameters. It also defines data objects for position data.

The central tool of the PNS is the program system to execute the tasks defined by the ECU. Simplified, the program system interprets the instructions of the task, calls the corresponding methods, calculates the demanded position and sends the data to the ECU.

For the definition of a task, the ECU generates a task resource. A task resource is mainly a list of instructions to call methods of the PNS or to call nested task resources. Parameters are defined by the ECU and placed in parameter resources. To store calculated position data, the ECU has to define data resources. The resources have to be transmitted from the ECU via the BUS to the PNS before activating corresponding tasks.

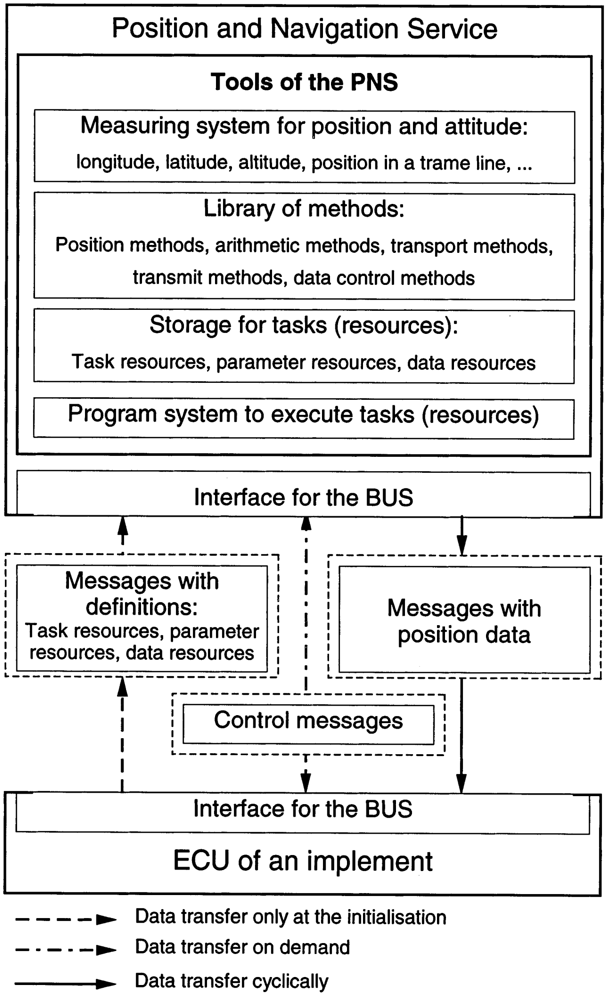

Fig. 3. Strcture of a PNS and its data exchange with one ECU.

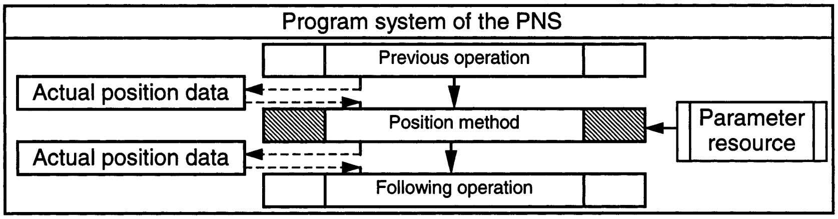

Fig. 4. Example of the use of a position method in the course of a task resource.

3.5. Predefined methods of the PNS

Predefined methods of the PNS are procedures to process position data or to control this data processing. Methods exist to perform different functions. The different methods are distinguished by a unique designator. They are called 'within tasks' (task resources). It will be a part of the standard to define the designators, function specifications and calling specifications of the methods.

3.5.1. Position methods

Position methods (methods to calculate position data) are the basis for calculating position data of target points. These methods calculate from an initial position (input position data, data of a reference point or previously computed data) the position of a new point (output position data, data of a target point or as an interim result). Position methods exist for different configurations (one-, two- or three-dimensional model considerations, rigidly coupled points, non-rigidly coupled points for several basic types of vehicles, implements and vehicle–implement combinations). These methods get their actual parameters (coordinates of the target point, vehicle length, width, height, type or wheelbases) from parameter resources which are defined by the concerned implement ECU.

Fig. 4 shows a section of a task resource using a position method. The program system of the PNS executes this task resource. At a certain part of the task resource, it finds a calling instruction for a position method. This calling instruction includes the designator of the specific method and a reference to a relevant parameter resource. At this moment, the program system owns actual position data, which result from previous operations. Now it uses these actual data as input data, and the parameter resource reference for the position method. Then, it executes the specified method. This method calculates the output position data using the specified parameters. It then returns to the program system. The output position data of the position method become the new actual position data. The program system continues and executes the following instructions.

3.5.2. Arithmetic methods

Arithmetic methods are used to compute mean, maximum, minimum or integral values of position data. An arithmetic method gets its input position data either from the actual position data of the program system or from a specified data resource. It computes the output position data using the parameters of a parameter resource determined in the calling instruction. Then it stores the results in a defined data resource.

Fig. 5 shows an example of the use of an arithmetic method. At a certain part of the task resource, the program system of the PNS finds a calling instruction for an arithmetic method. This calling instruction includes the designator of the specific method, a reference to a relevant parameter resource, a reference to a destination data resource and, optionally, a reference to a source data resource. The program system uses the actual data and the references for this method. Depending upon the calling specification, the arithmetic method receives its input data either from the program system (dashed line, no reference to a source data resource defined) or from a data resource (dashed dotted line, Data Resource I). It calculates the demanded values and stores the result in a data resource (Data Resource II). The parameters for the calculations are taken from the defined parameter resource. The method returns to the program system and continues. The actual position data are not altered.

3.5.3. Transport methods

Three types of transport methods are defined in the PNS. The import method is used to load the position data of a determined data resource as actual position data into the program system of the PNS. An export method stores the actual position data into a data resource predefined in the calling instruction. Import/export methods are needed to transfer position data from a source data resource to a destination data resource.

Fig. 6 shows an example of the use of an import and an export method. The calling instruction for an import method includes the designator of the specific method and a reference to a source data resource. Before executing an import method, the program system provides the reference of the source data resource for the method. The method is then operated and gets the position data, and returns it as actual position data to the program system. The previous actual position data are corrupted. The system continues. For the use of an export method, the actual position data and the destination data resource reference are provided. The export method puts the actual data into the destination data resource and returns to the program system. The actual position data are still valid.

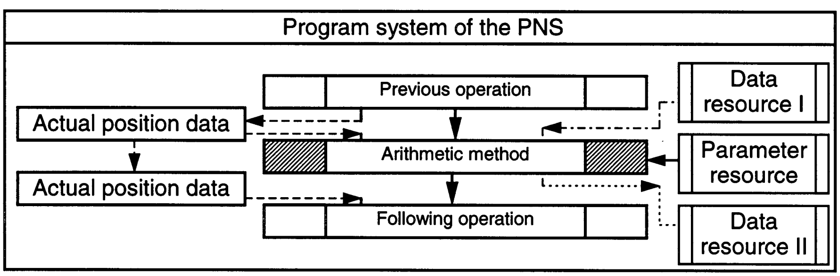

Fig. 5. Example of the use of an arithmetic method in the course of a task resource.

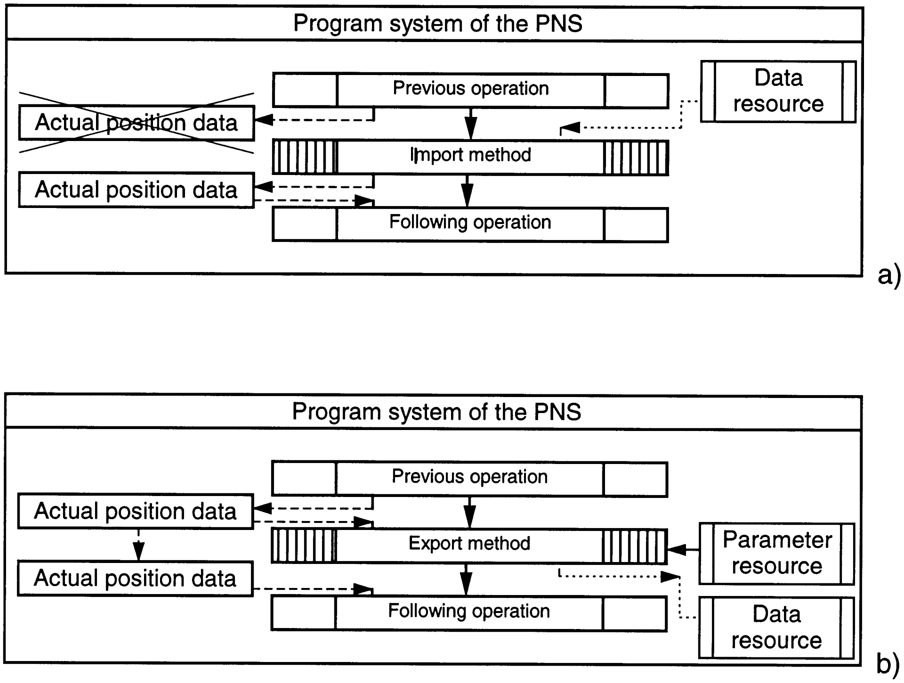

Fig. 6. Examples of the use of transport methods in the course of a task resource. (a) Import method; (b) export method.

3.5.4. Transmission methods

Transmission methods (transmit methods) serve to send specified position data to the ECU. The source of the data is defined in the calling instruction (either a data resource or the actual data of program system). When a transmit method is executed, it gets the specified position data and sends it to the ECU.

3.5.5. Data control methods

Data control methods control the execution of a task resource. The flow is either time or distance controlled. The program system of the PNS polls the task resource. If the determined time interval has expired or distance limits have been exceeded, it processes the following instructions. Otherwise, the program system skips to the end of the resource.

3.6. Definition of resources for the PNS

While methods are mostly predefined by the standard, resources are defined by the ECUs to use the tools of the PNS. Three types of resources exist.

3.6.1. Task resources

The first type of resources is task resources, data objects to describe tasks of the PNS. A task resource consists, at the very least, of the instructions Task Resource Beginning and Task Resource End. In between can be arbitrary sequences of an arbitrary number of Call Method and Call Resource instructions. The instructions Task Resource Beginning and Task Resource End include a unique designator of the resource. The calling instructions include the designators of the demanded methods or resources and controls or references to relevant parameter or data resources.

To perform a task by the PNS, the ECU has to activate a resource. This means the ECU selects a resource that shall be operated by the PNS. After the activation, the program system, of the PNS, processes all instructions called in the specific resource. The program system keeps temporal data during the operation, transfers it to the called methods or nested resources (on demand), and receives data from the called methods or nested resources.

The following sequence shows how the foregoing is expressed in a modified Backus–Naur format (BNF) syntax.

Task Resource :: =

< Task Resource Beginning >

{ < Call Method > | < Call Resource > }

< Task Resource End >

Below is a syntax describing the structure of a task resource, a modified BNF syntax:

<table>
<tr><th>Symbol</th><th>Meaning</th></tr>
<tr><td><symbol></td><td>Instruction</td></tr>
<tr><td>:: =</td><td>‘consists of’</td></tr>
<tr><td>{…}</td><td>Contents can appear from 0 to repeated times</td></tr>
<tr><td>Instr1|Instr2</td><td>Instruction 1 or Instruction 2</td></tr>
</table>

3.6.2. Data resources

In the PNS, data resources are needed to store position data for input and output purposes. The members of position data structures (data resources) include coordinates (longitude, latitude, altitude), directions (spatial angles), speeds or accelerations. The minimum definition of a data resource consists of the instructions Data Resource Beginning and Data Resource End. These instructions include a data resource type and a unique designator. An empty data resource provides a data object at which the PNS or the ECU can store position data. Otherwise, the ECU can set each data structure member with the instruction Set Data Structure Member. This instruction includes a member designator to specify the demanded structure member. Additionally, a position data structure includes the original position of the point for which the data are valid.

The following sequence shows a data resource in BNF syntax:
Data Resource :: =
< Data Resource Beginning >
{ < Set Data Structure Member > }
< Data Resource End >

3.6.3. Parameter resources

Parameter resources serve to contain parameter structures for different methods of the PNS. The members of parameter structures (parameter resources) depend on the type of methods that use the parameters. For position methods, parameter resources include members such as vehicle length, width, height and wheelbase. For arithmetic methods, parameter resources contain time intervals for averaging and integration or equivalent distances. Data control methods need parameters such as time intervals or working distances to start measurement and calculation of position data. Parameter resources are similar to data resources and defined by BNF syntax as follows:
Parameter Resource :: =
< Parameter Resource Beginning >
< Set Parameter Structure Member >
{ < Set Parameter Structure Member > }
< Parameter Resource End >

3.7. Basic rules and definitions of the PNS

For the operation of tasks, the following basic rules apply:

- Tasks are assembled in task resources.
- Task resources are defined by the requesting ECU (LBS participant).
- Task resources are distinguished by a unique ECU specific designator.
- An ECU loads its task resources into the PNS.
- An ECU can operate only its own resources.
- Task resources are an assemblage of calls of predefined methods of the PNS.
- Task resources can call other task resources.
- At the calling of a task resource, the source of input position data (either from an addressed data resource, inherited from the calling task resource or no input data) and the destination of output position data (either to an addressed data resource, returned to the calling resource or no destination) are established. At the beginning of the called task resource, actual position data are generated from the input position data. At the end of a task resource, actual position data of the resource are stored as output position data if a destination address is determined and/or is returned to the calling resource if needed.
- At the return from a called task resource, the actual position data of the calling resource are restored, except the returned data from the called task resource are demanded by the calling resource.
- Multiple nestings of task resources are allowed.
- Task resources have to be defined before their first use.

- Task resources can be activated and deactivated.
- All tasks included directly in a task resource and all tasks referenced in called task resources are executed after the activation.
- After deactivation, all tasks of a task resource are terminated. Tasks of referenced task resources may be active elsewhere.
- Task resources can be changed to their defined extent.

For the methods of the PNS, the following basic rules apply:

- There exists a pool of predefined methods in the PNS.
- Methods are distinguished by a unique designator.
- Methods are called inside of task resources.
- At the calling of a method, the source of parameters (address of selectable parameter resources) is determined. The method uses these parameters and the valid actual position data of the calling task resource (as input data) to calculate its output data.
- At the return from a called method, the output data become the actual position data of the calling resource.

For parameters, the following definitions are valid:

- Parameters represent a structure.
- Parameters are contained in parameter resources.
- Parameter resources are distinguished by a unique designator.
- Parameter structure members are distinguished by a unique designator.
- Parameters can be changed. After the amending of parameters, methods are executed with the new parameters.

For position data, the following definitions are valid:

- Position data represent a structure.
- A position data structure consists of several members (coordinates, directions, speed, acceleration, etc.).
- Position data are contained in data resources.
- Data resources are distinguished by a unique designator.
- Data structure members are distinguished by a unique designator.
- Data resources serve for the import and export of position data.

3.8. Operating task resources in the PNS

To start the operation of a task resource, a requesting ECU sends a single command to the PNS. This command specifies the demanded task resource with the resource designator. This task resource is the top-level resource, which will be operated by the program system of the PNS. Because it is not nested in a calling task resource, some special issues have to be regarded. If this entire task should be started cyclically, then a control method has to be put on the top of this resource. To get input data (no source is determined), the top-level resource has to call a transport method (import method). This import method has to get position data from a specific initial reference point. This is a virtual coupling point between the PNS and any ECU. The original task of the PNS is to provide this special reference data.

Now the program system is prepared to operate. At the call of a position method, the system transfers its actual position data to the method. This returns the computed data, now the new actual position data. At the call of an inserted task resource, the system either inherits the actual position data, transfers position data from a specified data resource to the called task resource or transfers no data, depending on the conditions in the calling instruction. After the return from an inserted task resource, the system accepts the returned data as actual position data or restores its own actual position data, also depending on the conditions in the call instruction. With the help of export methods, the actual position data or data from a determined source can be stored in a data resource, specified by the designator in the call instruction. Data can also be transmitted to the requesting ECU by calling a transmit method.

At the end of a resource, the actual data of the resource can be stored in a data resource defined by the destination designator in the call instruction. This is not possible for a top-level task resource, because in this situation no address is specified.

4. Example of the employment of the PNS

Fig. 7 shows a scheme of a tractor with a towed sprayer. In a first example, the position data of the front wheels shall be provided by the PNS. In a second example, the PNS shall provide the position data for a site-specific application of chemicals according to a task map.

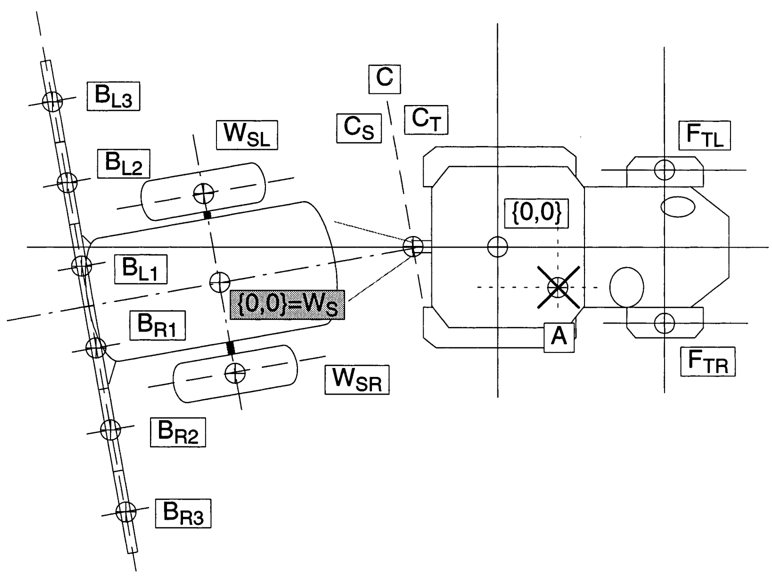

Fig. 7. Two-dimensional scheme of a tractor with a towed sprayer.

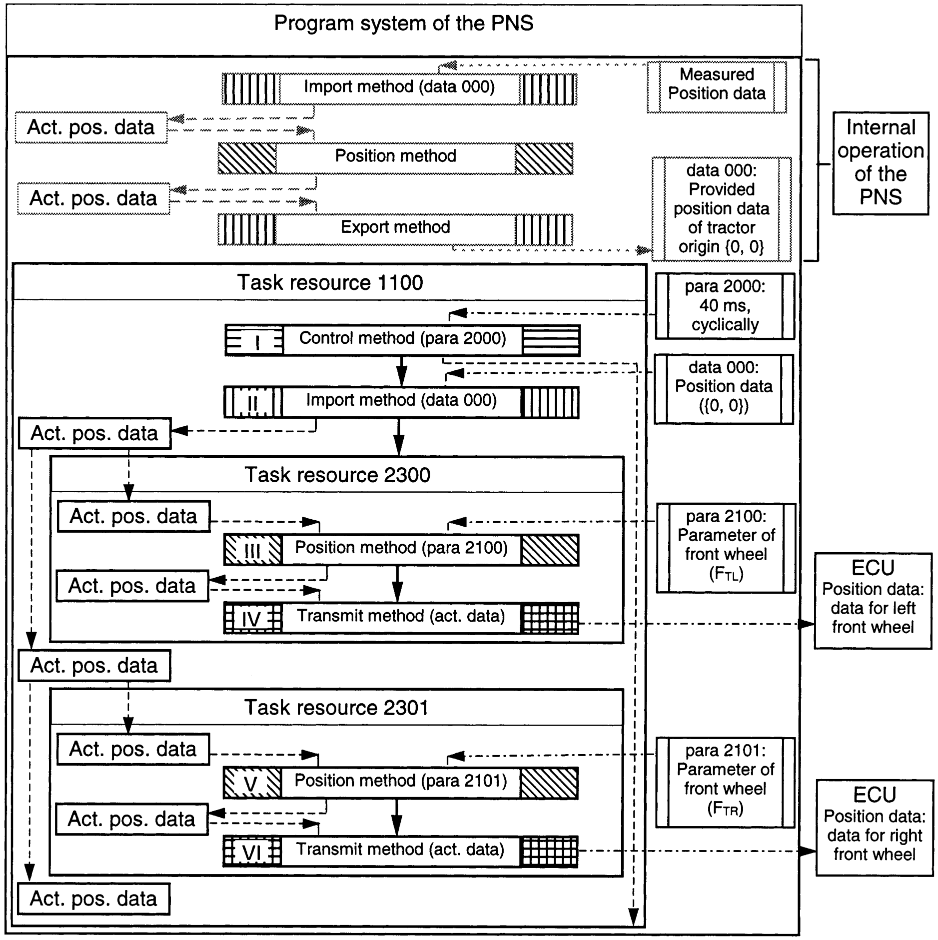

Fig. 8. Structure of an exemplary task resource for the tractor.

4.1. Example 1: position of the front wheels

The tractor has its coordinates with the origin at the point {0, 0}. Additionally, the measuring point (A) and the reference points for the front wheels (F_{TL} and F_{TR}) are defined for the tractor. The position data for the front wheels of the tractor are processed and cyclically transmitted in a time interval of 40 ms to the tractor ECU.

For this task, the ECU of the tractor has defined the resources. This is depicted in Fig. 8. These are the task resources (task resource 1100, 2300, 2301) and the parameter resources (para 2000, para 2100, para 2101). The task resource 1100 is the top-level resource. The task resource 1100 begins with a control method (I), which refers to a parameter resource (para 2000) and obtains parameters from it. The method controls the data processing of the task resource 1100 and restarts it cyclically every 40 ms; this means if the time interval has not expired, the task resource is skipped.

Otherwise, the following instructions of the resource are executed. Import method (II) imports from the PNS the position data (data 000) of its coupling point to the PNS. In this example, the origin $\{0, 0\}$ of the tractor's coordinates is defined as coupling point between tractor and PNS. These position data are set to the program system as actual position data (Position data $\{0, 0\}$) inside the task resource 1100.

The program system of the PNS is responsible for calculating these position data automatically. In an internal operation, the PNS gets the position data of the measuring point. Then it computes the position data of the coupling point $\{0, 0\}$. Necessary parameters such as the relative coordinates of the measuring point, e.g. antennas (A), have to be defined at the installation of the hardware of the PNS.

In task resource 1100, the task resource 2300 and 2301 are called. Task resource 2300 inherits the actual position data (Position data $\{0, 0\}$) from the calling resource (task resource 1100). The called position method (III) calculates the position data for the reference point of the left front wheel (F_{TL}) using the concerning parameters contained in the parameter resource (para 2100). The method returns its results to the calling task resources as new actual data. The following transmit method (IV) sends these data directly to the tractor ECU as position data for the left front wheel. The nested task resource 2300 ends and returns.

Task resource 1100 restores its actual position data for the next called task resource 2301. This task resource provides the position data for the right front wheel with an analogous procedure. The operation stops at the end of task resource 1100 until the next cycle.

4.2. Example 2: position of sprayer sections

The first example only uses a small part of the functionality of a PNS. The second example is a little more complex. In addition to the coordinates of the first example, some more reference or target points (Fig. 7) have to be considered. Very important is the point of the coupling ($C = C_{\mathrm{T}} = C_{\mathrm{S}}$) which is owned by the sprayer as well as by the tractor. The position data of this point are the starting data for all tasks that can be defined by the sprayer (requesting ECU). The second important point is the middle of the sprayer axle (W_{S}). Its position and attitude data describe the movement of the sprayer completely. On this basis, it is very simple to calculate the position data of any rigidly coupled point of the sprayer such as sections of the sprayer boom or wheels.

To specify the locations of reference or target points, the sprayer has also its coordinates with the origin at the point ($\{0, 0\} = W_{\mathrm{S}}$) (grey background). Reference points exist for the wheels (W_{SL} and W_{SR}) and the sections of the spray boom (B_{L3}, B_{L2}, B_{L1}, B_{R3}, B_{R2}, B_{R1},).

The basic task definitions of this example are as follows:

Averaged position data for the origin (W_S) of the sprayer have to be transmitted to the sprayer in a predefined time interval of 10 s. The sampled position data of the boom sections have to be transmitted every second.

The program system of the PNS provides in an internal operation the position data of the coupling automatically (Fig. 9). In addition to example 1, the PNS has to know the parameters of the coupling (C_T) of the tractor. This information must be provided by the tractor ECU.

For the demanded tasks, the requesting ECU of the sprayer has defined several resources. The structure of these task resources with the called resources is shown in Fig. 9. The ECU has defined the task resources (task resource 100, 200, 210, 313, 312, 311, 321, 322, 323), the parameter resources (para 1000, para 0900, para 0910, para 1010, para 1100, para 0113, para 0112, para 0111, para 0121, para 0122, para 0123) and the data resources (data 000, data 0800).

In this implementation task, resource 100 is the top-level resource. The sprayer has activated this resource. The task resource 100 begins with a control method (1). This method refers to a parameter resource (para 1000) and obtains necessary parameters from it. The method controls the data processing of the top-level task resource and restarts it cyclically with a time interval of 50 ms. The following import method (2) imports the position data (data 000) of the coupling ($C = C_S = C_T$) from the PNS. These position data are set to the program system as actual position data (Position data C) inside the task resource 100. The next position method (3) computes, from these actual data, the position data of the axle (reference point W_S) and returns it to the system (Position data W_S). The arithmetic method (4) calculates a mean value (Position data W_S) from these data and stores it in the data resource (data 0800).

The next instruction calls the task resource 200. If the determined time interval (10 s, controlled by control method (5), with reference to parameter resource para 1010) has expired, the PNS transmits the data of the data resource (data 0800, mean value of axle) to the ECU of the sprayer. It uses the transmit method (6) for this operation. Otherwise, this resource is skipped. Task resource 200 has no influence on the actual position data of task resource 100.

At the next place, the task resource 210 is called. This task resource inherits actual position data from the calling resource. If the determined time interval (1 s, controlled by control method (7), with reference to parameter resource para 1100) has not expired, task resource 210 is skipped. Thereby, task resource 100 ends until the next cycle is started.

Otherwise, the following instructions are executed. Task resource 313 inherits the actual position (Position data W_s). The called position method (8) calculates the position data for the reference point of the left boom section (B_{L3}) using the parameters of section B_{L3} (para 0113). The method returns its results to the calling task resource (task resource 313) as actual position data. With the help of the following transmit method (9), these data are transmitted to the sprayer (Position data B_{L3}). Task resource 313 ends and returns to the calling task resource (task resource 210). This task resource restores its actual position data (Position data W_S) for the following operations.

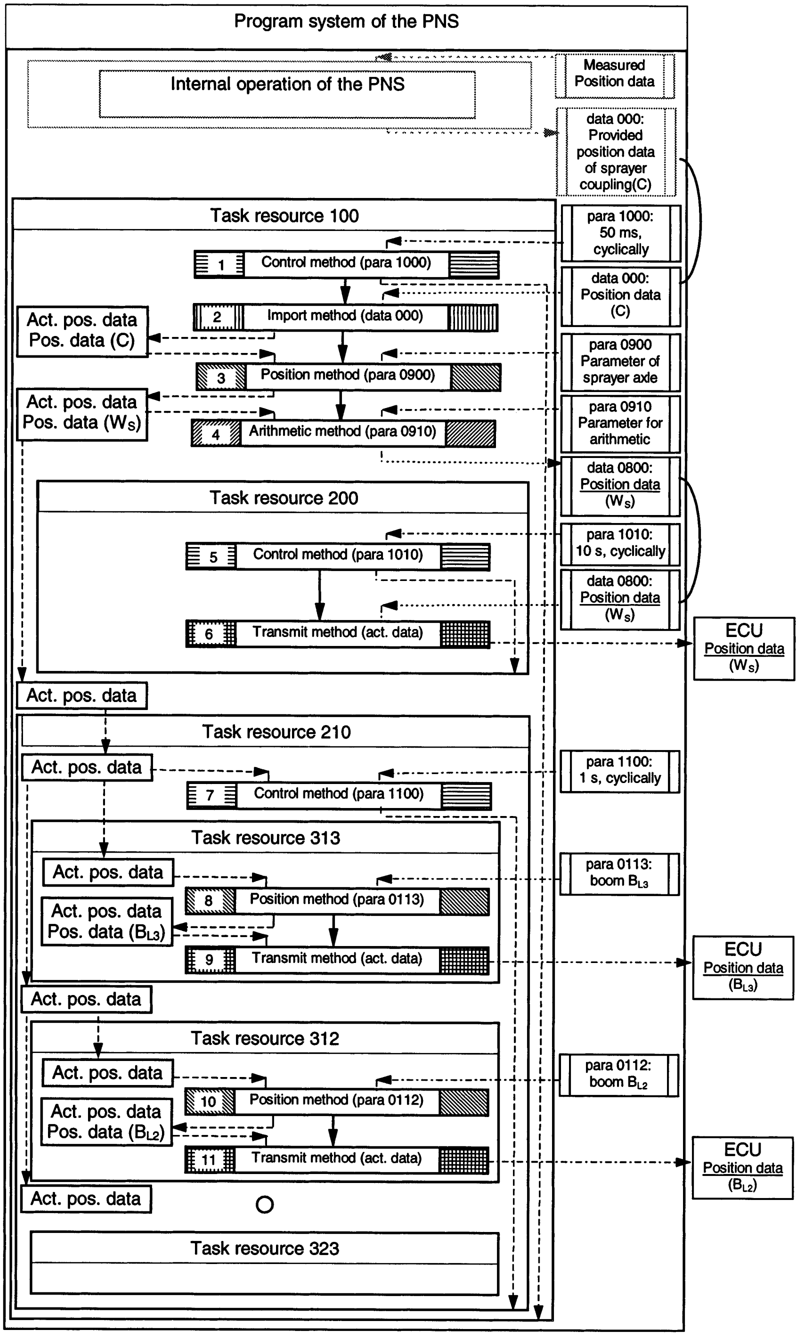

Fig. 9. Structure of an exemplary task resource for the sprayer.

An analogous procedure is executed for the following task resources (task resource 312, 311, 321, 322, 323) to calculate and transmit the position data for the other reference points of the sprayer boom. The operation stops at the end of task resource 100 until the next cycle is started.

5. Final remarks

A conclusion of the paper is not possible because the presented description of a positioning and navigation service is still a proposal. The explanations show the main conditions necessary to provide and exchange position data in a network for field machinery. The paper provides a basis for further discussion, which has the goal to make measured and calculated position data in an adapted and compatible form available for all components and purposes of mobile agricultural machine combinations.

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